

**DEVICE AND METHOD FOR EMITTING COMPOSITE OUTPUT
LIGHT USING MULTIPLE WAVELENGTH-CONVERSION
MECHANISMS**

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BACKGROUND OF THE INVENTION

- [0001] Conventional light sources, such as incandescent, halogen and fluorescent lamps, have not been significantly improved in the past twenty years.
- 10 However, light emitting diode (“LEDs”) have been improved to a point with respect to operating efficiency where LEDs are now replacing the conventional light sources in traditional monochrome lighting applications, such as traffic signal lights and automotive taillights. This is due in part to the fact that LEDs have many advantages over conventional light sources. These advantages include
- 15 longer operating life, lower power consumption, and smaller size.
- [0002] LEDs are typically monochromatic semiconductor light sources, and are currently available in various colors from UV-blue to green, yellow and red. Due to the narrow-band emission characteristics, monochromatic LEDs cannot be directly used for “white” light applications. Rather, the output light of a
- 20 monochromatic LED must be mixed with other light of one or more different wavelengths to produce white composite light. Some conventional LEDs include a wavelength-conversion mechanism to convert some of the original light generated by the LEDs into longer different wavelength light, which combines with the original light to produce white composite light. One such type of LEDs
- 25 of interest uses an LED die with a fluorescent substrate as the wavelength-conversion mechanism to convert the light emitted from an active layer of the LED die into longer wavelength light. As an example, the active layer of the LED die may be Gallium Indium Nitride (GaN) active layer that emits light having a peak wavelength of approximately 430 nm, and the fluorescent substrate of the
- 30 LED die may be a Gallium Nitride (GaN) substrate doped with oxygen, carbon or nitrogen vacancy that converts some of the light emitted from the GaN active layer into light having a peak wavelength of approximately 550 nm.

[0003] A concern with the conventional LEDs that use a fluorescent substrate as a wavelength-conversion mechanism is that the resulting white composite light from the LEDs may be deficient in certain wavelengths, e.g., in the red wavelength range of the visible spectrum (~620 nm to ~800 nm). As such,

5 these LEDs do not have high color rendering characteristics.

[0004] Another concern is that since the original light and the converted light originate from different locations within an LED die, the original light and the converted light may not blend together well, resulting in a composite light that has a non-homogeneous color. As an example, the composite output light from

10 the central portion of the LED may appear bluer than the light from the perimeter of the LED.

[0005] In view of these concerns, there is a need for an LED and method for emitting white composite light with high color rendering characteristics and more homogeneous color.

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SUMMARY OF THE INVENTION

[0006] A device and method for emitting composite output light uses multiple wavelength-conversion mechanisms to convert the original light generated by a light source of the device into longer wavelength light to produce

20 the composite output light. One of the wavelength-conversion mechanisms of the device is a fluorescent substrate of the light source that converts the original light into first converted light. Another wavelength-conversion mechanism of the device is a wavelength-conversion region optically coupled to the light source that converts the original light into second converted light. The original light, the first converted light and the second converted light are emitted from the device as components of the composite output light.

[0007] A device for emitting composite output light in accordance with an embodiment of the invention includes a light source and a wavelength-conversion region. The light source emits original light. The light source includes a

30 fluorescent layer having a property to convert some of the original light into first converted light. The wavelength-conversion region is optically coupled to the light source to receive some of the original light and the first converted light. The

wavelength-conversion region includes a fluorescent material having a property to convert some of the original light into second converted light. The original light, the first converted light and the second converted light are components of the composite output light.

5 [0008] A method for emitting composite output light includes generating original light within a light source, converting some of the original light into first converted light within the light source, converting some of the original light into second converted light outside of the light source, and emitting the original light, the first converted light and the second converted light as components of the
10 composite output light.

[0009] Other aspects and advantages of the present invention will become apparent from the following detailed description, taken in conjunction with the accompanying drawings, illustrated by way of example of the principles of the invention.

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BRIEF DESCRIPTION OF THE DRAWINGS

20 [0010] Fig. 1 is a diagram of a light emitting diode (LED) having two wavelength-conversion mechanisms in accordance with an embodiment of the invention.

[0011] Fig. 2 shows light from different regions of the LED of Fig.1, including converted light from the fluorescent substrate and the wavelength-conversion region of the LED.

25 [0012] Figs. 3A and 3B are diagrams of LEDs with alternative wavelength-conversion region configurations in accordance with an embodiment of the invention.

[0013] Figs. 4A and 4B are diagrams of LEDs with a planar wavelength-conversion region in accordance with an alternative embodiment of the invention.

30 [0014] Fig. 5 is a flow diagram of a method for emitting composite output light in accordance with an embodiment of the invention.

DETAILED DESCRIPTION

[0015] With reference to Fig. 1, a light emitting diode (LED) 100 in accordance with an embodiment of the invention is shown. The LED 100 is 5 designed to produce composite output light using multiple wavelength-conversion mechanisms. As an example, the composite output light produced by the LED 100 may be “white” output light. The white output light is produced by converting some of the original light generated by the LED 100 into longer wavelength light using the wavelength-conversion mechanisms. The use of 10 multiple wavelength-conversion mechanisms can produce composite output light having a more homogeneous color and/or higher color rendering characteristics than conventional LEDs that use only a single wavelength-conversion mechanism, e.g., a fluorescent substrate.

[0016] As shown in Fig. 1, the LED 100 is a leadframe-mounted LED. The 15 LED 100 includes an LED die 102, leadframes 104 and 106, a wire 108 and a lamp 110. The LED die 102 is a semiconductor chip that functions as a light source for the LED 100. The LED die 102 includes a fluorescent substrate 112 and a number of layers formed over the fluorescent substrate, including an active layer 114. The active layer 114 is the layer of the LED die 102 from which light 20 is generated. This light is sometimes referred to herein as the original light or the original emitted light. The wavelength of the original light emitted from the active layer 114 depends primarily on the materials used to form the LED die 102. As an example, the LED die 102 may be configured such that the active layer 114 generates blue light (peak wavelength of approximately 430 nm), which can be 25 converted into lower energy (longer wavelength) light using fluorescence. The other layers formed over the fluorescent substrate 112 are those commonly found in LEDs, such as buffer layers, cladding layers and contact layers. As such, these layers are not described herein in detail.

[0017] The fluorescent substrate 112 of the LED die 102 is the first 30 wavelength-conversion mechanism included in the LED 102. The fluorescent substrate 112 converts some of the original light emitted from the active layer 114 of the LED die 102 into longer wavelength light. The fluorescent substrate 112 may be a semiconductor or insulating substrate that has been doped with one or

more impurities. As an example, the fluorescent substrate 112 may be a Gallium Nitride (GaN) substrate doped with oxygen, carbon or nitrogen vacancy.

However, the fluorescent substrate 112 can be any substrate that has a fluorescent property to convert the original light emitted from the active layer 114 into longer wavelength light.

[0018] The LED die 102 is situated on the leadframe 104. In the illustrated embodiment, the top surface of the leadframe 104 on which the LED die 102 is positioned is a planar surface. However, in another embodiment, the top surface of the leadframe 104 includes a reflector cup (not shown), or a reflective 10 depressed region, in which the LED die 102 is positioned. The LED die 102 is electrically connected to the other leadframe 106 via the wire 108. In this illustrated embodiment, the fluorescent substrate 112 of the LED die 102 is electrically connected to the leadframe 104. In another embodiment, the LED die 102 is electrically connected to the leadframe 104 via a second wire (not shown).
15 The use of the second wire is dependent on the type of LED die 102. The leadframes 104 and 106 provide the electrical power needed to drive the LED die 102. The LED die 102 is encapsulated in the lamp 110, which is a medium for the propagation of light from the LED die 102. The lamp 110 includes a main section 116 and an output section 118. In this embodiment, the output section 118 of the
20 lamp 110 is dome-shaped to function as a lens. Thus, the light emitted from the LED 100 as output light is focused by the dome-shaped output section 118 of the lamp 110. However, in other embodiments, the output section 118 of the lamp 100 may be horizontally planar.

[0019] The lamp 110 of the LED 100 is made of a transparent substance, 25 which can be any transparent material such as clear epoxy, so that light from the LED die 102 can travel through the lamp and be emitted out of the output section 118 of the lamp. As shown in Fig. 1, the lamp 110 includes a wavelength-conversion region 120, which is also a medium for propagating light. That is, light from the LED die 102 is able to travel through the wavelength-conversion
30 region 120. The wavelength-conversion region 120 includes fluorescent material 122, which has a property to convert some of the original light emitted by the LED die 102 into lower energy (longer wavelength) light. The fluorescent material 122 in the region 120 absorbs some of the original light from the LED die

102, which excites the atoms of the fluorescent material, and emits the longer wavelength light. The wavelength-conversion region 120 is the second wavelength-conversion mechanism included in the LED 100.

[0020] As illustrated in Fig. 1, the wavelength-conversion region 120 surrounds the LED die 102. Consequently, the wavelength-conversion region 120 encloses the LED die 102 over the top surface of the leadframe 104. Thus, in this embodiment, the light from the LED die 102, whether the light is the original light from the active layer 114 of the LED die or the converted light from the fluorescent substrate 112, propagates through the wavelength-conversion region 120 to be emitted from the LED 100 as output light. Although the wavelength-conversion region 120 is shown in Fig. 1 as having a uniform thickness, the wavelength-conversion region may have an irregular or varying thickness.

[0021] In the illustrated embodiment, the fluorescent material 122 included in the wavelength-conversion region 120 includes one or more inorganic phosphors or nano-phosphors in the form of particulates. The typical size of inorganic phosphor particulates range from 1 to 50 micrometers, while the typical size of nano-phosphor particulates range from 1 to 100 nanometers. As an example, the fluorescent material 122 used in the wavelength-conversion region 120 may be Europium activated Strontium Sulfide (SrS), which converts the original light (e.g., blue light) into red light (i.e., peak wavelength in the red region of the optical spectrum), Europium activated Strontium Thiogallate (SrTG:Eu), which converts the original light into green light (i.e., peak wavelength in the green region of the optical spectrum) and/or Cerium activated Yttrium Aluminum Garnet (YAG:Ce), which converts the original light into yellow light (i.e., peak wavelength in the yellow region of the optical spectrum). However, any phosphor or combination of phosphors can be used, including nano-phosphors, as long as the phosphors are activated by the original light emitted from the active layer 114 of the LED die 102.

[0022] In an alternative embodiment, the fluorescent material 122 of the wavelength-conversion region 120 includes one or more fluorescent organic dyes or any combination of fluorescent organic dyes, inorganic phosphors and nano-phosphors. The type of fluorescent material 122 included in the wavelength-conversion region 120 can be selected to enhance or supplement color

components of the composite output light of the LED 100. Thus, the fluorescent material 122 of the wavelength-conversion region 120 may convert the original emitted light from the active layer 114 of the LED die 102 into light having a peak wavelength that differs from the peak wavelength of the light converted by the

5 fluorescent substrate 112. In other words, the fluorescent material 122 of the wavelength-conversion region 120 may be selected to convert the original emitted light from the active layer 114 of the LED die 102 into light having a peak wavelength near a region of the visible light spectrum that is deficient when only the original light and the converted light from the fluorescent substrate 112 of the

10 LED die 102 are combined to produce a composite light. However, the fluorescent material 122 of the wavelength-conversion region 120 may be selected to convert the original emitted light from the active layer 114 of the LED die 102 into light having the same or substantially same peak wavelength as the converted light from the fluorescent substrate 112.

15 **[0023]** The lamp 110 with the wavelength-conversion region 120 can be fabricated using a variety of methods. In one embodiment, the fluorescent material 122 is mixed with epoxy and then placed over the LED die 102, forming the wavelength-conversion region 120. In another embodiment, the fluorescent material 122 is mixed with molding compound, e.g., clear plastic compound, and

20 is transfer molded over the LED die 102, forming the wavelength-conversion region 120. In either embodiment, the rest of the lamp 110 can be formed over the LED die 102 and the wavelength-conversion region 120 using a conventional method, such as transfer molding or casting.

25 **[0024]** In operation, the LED 102 generates composite output light using both the fluorescent substrate 112 of the LED die 102 and the wavelength-conversion region 120 of the lamp 110 as two distinct wavelength-conversion mechanisms. When the LED 100 is activated, i.e., current is injected into the LED die 102 through the leadframes 104 and 106, original light is emitted from the active layer 114 of the LED die in all directions, as illustrated by the light on paths 230, 232, 234, 236, 238, 240 and 242 in Fig. 2. The original light has a spectrum peak at a first wavelength, e.g., at 430 nm. Some of the original light emitted downward into the fluorescent substrate 112 is converted into longer wavelength light by the fluorescent substrate, as illustrated by the light on path

244. This converted light has a spectrum peak at a second wavelength, e.g., at 550 nm. However, some of the original light emitted into the fluorescent substrate 112 propagates through the fluorescent substrate without being converted into longer wavelength light, as illustrated by the light on paths 234 and 238. Thus, some of
5 the light emitted out of the fluorescent substrate 112 is the original light from the active layer 114 of the LED die 102.

[0025] The remaining original light from the active layer 114 of the LED die 102 is emitted out of the LED die without propagating through the fluorescent substrate 112, as illustrated by the light on paths 230, 232, 240 and 242. In this
10 embodiment, since the LED die 102 is covered by the wavelength-conversion region 120 of the lamp 110 over the leadframe 104, the original light emitted out of the LED die that has or has not propagated through the fluorescent substrate 112 travels into the wavelength-conversion region. Some of this original light is then converted into longer wavelength light by the fluorescent material 122 of the
15 wavelength-conversion region 120, as illustrated by the light on paths 246, 248 and 250. This converted light has a spectrum peak at a third wavelength, e.g., at 650 nm. Thus, light emitted out of the wavelength-conversion region 120 includes the original light, as illustrated by the light on path 230 and 238, and the converted light from the wavelength-conversion region 120, as illustrated by the
20 light on paths 246, 248 and 250, as well as the converted light from the fluorescent substrate 112 of the LED die 102, as illustrated by the light on path 244. Consequently, the original light from the active layer 114, the converted light from the fluorescent substrate 112 of the LED die and the converted light from the wavelength-conversion region 120 of the lamp 110 are emitted as
25 components of the composite output light of the LED 100.

[0026] Due to the converted light from the wavelength-conversion region 120, which in one embodiment has a peak wavelength that differs from the peak wavelength of the original light emitted from the active layer 114 of the LED die 102 and the peak wavelength of the converted light from the fluorescent substrate
30 112 of the LED die, the composite output light of the LED 100 may have a broader spectrum than the composite output light of a conventional LED that uses a fluorescent substrate as the only wavelength-conversion mechanism.
Furthermore, if phosphor particulates are used in the wavelength-conversion

region 120 as the fluorescent material 122, then the phosphor particulates also function to scatter the original light and the converted light from by the fluorescent substrate 112 to better blend or mix the original light and the converted light so that the composite output light of the LED 100 has a more
5 homogeneous color.

[0027] Turning now to Figs. 3A and 3B, LEDs 300A and 300B with alternative wavelength-conversion region configurations in accordance with an embodiment of the invention are shown. In these figures, same reference numerals of Fig. 1 are used to identify similar elements. The LED 300A of Fig.
10 3A includes a lamp 310A in which a wavelength-conversion region 320A is located between the LED die 102 and the outer surface of the lamp. The wavelength-conversion region 320A has a configuration of a square or rectangular box positioned on the top surface of the leadframe 104 over the LED die 102. Thus, the wavelength-conversion region 320A is configured to substantially
15 enclose the LED die 102 over the leadframe 104. The LED 300B of Fig. 3B includes a lamp 310B in which a wavelength-conversion region 320B is also located between the LED die 102 and the outer surface of the lamp. However, the wavelength-conversion region 320B of the LED 300B has a configuration of a hemispheric shell positioned on the top surface of the leadframe 104 over the LED
20 die 102. Thus, the wavelength-conversion region 320B is also configured to substantially enclose the LED die 102 over the leadframe 104. The lamps 310A and 310B with the wavelength-conversion regions 320A and 320B, respectively, can be fabricated by any practical combination of depositing epoxy with or without the fluorescent material 122 over the LED die 102 and transfer molding a
25 mold compound or casting an epoxy with or without fluorescent material 122 over the LED die.

[0028] Turning now to Figs. 4A and 4B, LEDs 400A and 400B with a planar wavelength-conversion region in accordance with an alternative embodiment of the invention are shown. The LED 400A of Fig. 4A includes a
30 lamp 410A in which a wavelength-conversion region 420A is a planar layer positioned on the LED die 102. The size of the fluorescent layer 420A may be the same as the LED die 102 or larger, as illustrated in Fig. 4A. The LED 400B of Fig. 4B includes a lamp 410B in which a wavelength-conversion region 420B is a

- planar layer positioned over the LED die 102, but not on the LED die. Thus, there is a region of transparent material between the LED die 102 and the fluorescent layer 420B. Similar to the fluorescent layer 420A of the LED 400A, the size of the fluorescent layer 420B may be the same as the LED die or larger. The lamps 5 410A and 410B with the wavelength-conversion regions 420A and 420B, respectively, can also be fabricated by any practical combination of depositing epoxy with or without the fluorescent material 122 over the LED die 102 and transfer molding a mold compound or casting an epoxy with or without fluorescent material 122 over the LED die.
- 10 [0029] The different wavelength-conversion region configurations described above can be applied to other types of LED devices, such as surface-mounted LED devices, to produce other types of LED devices with multiple wavelength-conversion mechanisms in accordance with the invention. In addition, these different wavelength-conversion region configurations may be applied to other 15 types of light emitting devices, such as semiconductor lasing devices, to produce other types of light emitting device in accordance with the invention.
- [0030] A method for emitting composite output light in accordance with an embodiment of the invention is described with reference to a flow diagram of Fig. 5. At block 502, original light is generated within a light source, which may be an 20 LED die. Next, at block 504, some of the original light is converted into first converted light within the light source, e.g., by a fluorescent substrate of the light source. Next, at block 506, some of the original light is converted into second converted light outside of the light source, e.g., by a fluorescent region optically coupled to the light source. Next, at block 508, the original light, the first 25 converted light and the second converted light are emitted as the components of the composite output light.
- [0031] Although specific embodiments of the invention have been described and illustrated, the invention is not to be limited to the specific forms or arrangements of parts so described and illustrated. The scope of the invention is 30 to be defined by the claims appended hereto and their equivalents.